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13. ABSTRACT *(Maximum 200 words)*

The research for this grant is on fundamental problems in the design of heterogeneous networks, including high level wireless link modeling, resource negotiation, and end-to-end transport.

TCP, the de facto standard for Internet data transport protocol, is not robust to lossy wireless links. However, it has been shown that it is possible to support TCP by hiding the wireless loss from it using link layer error recovery. Also, alternatives transport protocol have been investigated, which solve the congestion control and error recovery problems of TCP. Quality of Service (QoS) for real time data have also been investigated. Choice of forward error control (FEC) and adaptation to the channel have been shown to improve the QoS provided. Also, a generalized round robin scheduler has been shown to provide the same QoS at lower complexity.

Note: the PI has moved from University of Illinois to University of California Santa Barbara, where he is continuing his work under a new grant.

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Final Report: Grant ARO DAAG55-98-1-0219

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1 Overview

The research for this grant is on fundamental problems in the design of heterogeneous networks, including network level wireless link modeling, resource negotiation, and end-to-end transport. This work continues prior work in the area by the PI under a multi-university Focused Research Initiative (FRI) program administered by ARO, under grant DAAH04-95-1-0246, which ended in 1998.

The PI has moved from the University of Illinois, to which the grant was originally awarded, to the University of California, Santa Barbara (UCSB). In order to transfer the funds remaining in the grant from Illinois to UCSB, we have requested termination of the Illinois grant effective March 1, 2000, and we will reapply for the amount remaining in the grant (which is scheduled to terminate in 2001) from UCSB. This is a final report on the work performed on the grant while the PI was at Illinois.

1.1 Personnel on Grant

The PI, Prof. Madhow, moved from Illinois to UCSB in December 1999. He is in the process of building a wireless communications group at UCSB, and continuation of the research on this grant is an important part of this effort.

Students at Illinois: Hemant Chaskar, who was funded through the FRI program as well as this grant, completed his Ph. D. at the University of Illinois in May 1999, and subsequently joined a position in Nokia Research Labs in Boston. Julian Waldby, also funded through the FRI program and this grant, passed his Ph. D. Preliminary Examination at the University of Illinois in June 1999. Julian is currently on a personal leave of absence from the University of Illinois, and plans to return in Summer 2000 to complete his Ph. D. We plan to subcontract from UCSB to Illinois to support him over the summer. Julian's research is at an advanced stage, and is supervised through email and phone conversations, as well through periodic visits back to Illinois by the PI.

Students at UCSB: Once the funds are transferred, two students will start working on the grant at UCSB, one in the spring quarter, and another in the summer. The focus of their effort will be on the design and validation of adaptive data and real-time applications over multihop wireless networks.

2 Accomplishments

A key feature of the research performed in this grant is that an understanding of wireless physical layer issues is applied to the design of the link, network, and transport layers. Copies of publications related to this contract are attached to this report.

TCP over Wireless: Most Internet data applications run on top of TCP/IP, the de facto standard Internet data transport protocol. It is therefore crucial to be able to support TCP seamlessly over both wireless and wireline networks. Since TCP interprets any loss to be due to congestion, and drops its sending rate in response, its performance over a lossy wireless environment can be disastrous. We have shown, however, that it is possible to support TCP over wireless by hiding wireless loss from it by means of an appropriate link layer error recovery scheme. While many researchers have looked at this problem, our work provides the first analytical approach to design of the wireless-wireline interface. This work has recently appeared in the IEEE/ACM Transactions on Networking [2]. This work was in collaboration with a researcher at Lucent Technologies, and the student involved was Hemant Chaskar.

Real-time traffic over wireless: The issue of providing Quality of Service (QoS) guarantees to real time traffic was investigated through the example of a Rayleigh faded wireless downlink. Methods for statistical multiplexing were considered, and it was shown that QoS provisioning in this context requires consideration of traffic statistics, choice of link layer error recovery scheme, as well as wireless channel statistics. To the best of our knowledge, this is the first work that provides detailed consideration of all these factors, and shows how important joint optimization across all the system parameters is for efficient design. A journal paper on this topic has been submitted [3]. The student involved was Hemant Chaskar.

Generalized round robin: Much effort has been devoted to scheduling algorithms for both wireless and wireline networks that guarantee per connection quality of service. Most of this work is based on the weighted fair queueing paradigm. We have shown the surprising result that an alternative approach, which generalizes the classical round robin scheduler, can be used to provide the same level of quality of service at much lower complexity. This work has appeared in a conference publication [1], and has recently been submitted to a journal [4].

Beyond TCP: a new data transport protocol: We have developed a new transport protocol for heterogeneous networks which is much more robust than TCP/IP to random loss. This protocol is based on a system-theoretic view of what is required to solve the two key problems of data transport: congestion control and error recovery. This work was presented in an invited paper at the 1999 Communication Theory workshop [5]. Preliminary versions of these ideas were tried out under the FRI program, and were published in conferences. A journal paper on the latest version of the protocol is in preparation. The student involved in this work is Julian Waldby.

Real time Internet data transport: We have developed methods for reliable real-time data transport over the Internet based on adaptive forward error control coding. Algorithms for estimating the amount of code redundancy required to attain a desired Quality of Service have been obtained. The student involved is Julian Waldby.

3 Future Work

Julian Waldby expects to complete his Ph. D. over the summer of 2000. We anticipate that two journal papers will be submitted based on this research, and are also considering potential commercialization of the protocol ideas in his thesis to make communications software for supporting multimedia applications over a heterogeneous network.

The new work to begin at UCSB will be described in detail in the work statement for the funding request from UCSB. It will consist of two main thrusts:

1) A measurement-based approach to quality of service over wireless: Unlike our previous work [3],

which explicitly modeled the link and physical layer for resource provisioning, our objective here is to develop adaptive approaches to admission control and resource allocation/utilization. The idea is that the link scheduling mechanisms, as well as the traffic sources, would adapt in a decentralized fashion, depending on network conditions as well as application requirements. While the adaptive mechanisms will not depend on the underlying physical and link layer technology, their performance will be evaluated using detailed physical and link layer modeling (e.g., using frequency-hop or direct sequence CDMA).

2) Spatial multiplexing: As shown by researchers at Lucent Technologies [6], it is possible to obtain significant capacity gains in wireless systems in which antenna arrays are available both at the transmitter and the receiver. However, this so-called BLAST system has been demonstrated only in stationary, indoor wireless environments. In view of the exciting potential of this technology, we are modifying our goals in the original proposal to evaluate its applicability to military communications. Thus, our objective is to study whether these gains can be obtained in a harsher mobile environment as well, and if so, how one would exploit this physical layer breakthrough from a networking standpoint.

References

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